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Wave Runup on a 1 on 10 Slope

by
John Ahrens

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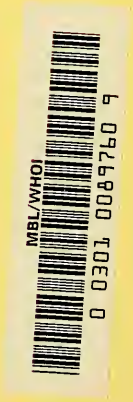

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This study was directed towards comparing the runup caused by monochromatic and simple irregular waves on a smooth 1 on 10 slope. Wave runup was measured by use of a modified step-resistance wave gage which gave reliable measurements of extreme values and also provided a complete time history of the runup-air interface on the slope. Irregular waves caused considerably higher extreme values of runup than monochromatic waves even when runup was normalized by dividing by the standard deviation of the incident wave water

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20. Abstract. (Continued)

surface displacement. The research is of a preliminary nature, and the findings are being used to develop a comprehensive wave runup and overtopping study to be conducted at CERC's new facilities at Fort Belvoir, Virginia.

PREFACE

This report is published to assist coastal engineers in the planning, design, and construction of shore structures. The results of this research are being used to develop plans for the future research on wave runup and overtopping. The work was carried out under the coastal construction research program of the U.S. Army Coastal Engineering Research Center (CERC).

The report was prepared by John P. Ahrens, Special Projects Branch, under the general supervision of Dr. Robert M. Sorensen, Chief, Special Projects Branch, Research Division.

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Comments on this publication are invited.

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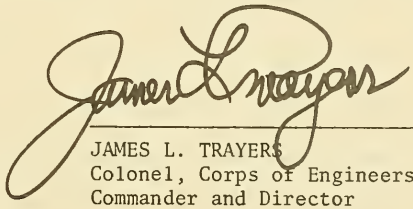

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SYMBOLS AND DEFINITIONS

D(max)	Elevation of highest wave crest above the mean water level
D_{rms}	Root mean square water surface displacement
ε	Spectral width parameter
H	Wave height
$\overline{H}$	Average wave height
H(max)	Maximum wave height
H_s	Average of the highest one-third of the wave heights
N_c	Number of wave crests in a length of wave record
N_R	Number of runup crests
N_z	Number of zero up-crossings in a length of wave record
P_x	Pressure head, in feet of water relative to stillwater level, which is exceeded x percent of the time
R	Wave runup, average of the runup crests
R(max)	Maximum runup
R_x	Vertical elevation above stillwater level which is exceeded x percent of the time by runup
SWL	Stillwater level
T	Wave period
T_z	Mean zero up-crossing wave period

WAVE RUNUP ON A 1 ON 10 SLOPE

by

John Ahrens

I. INTRODUCTION

This study was initiated in 1970 to investigate the runup of irregular waves. To make the results of the study useful to engineers who design shore structures, part of the research effort was directed at comparing the runup of irregular waves to the runup of monochromatic waves. A gage for measuring wave runup was also developed and tested. These efforts help relate the results to wave runup design curves presently available, and provide insight into the runup phenomenon. A prime objective of the study is to identify the characteristics of natural waves which are needed to predict runup or overtopping on a given structure. These results are being used to plan a comprehensive study of runup and overtopping to be conducted at the Coastal Engineering Research Center's (CERC) new facilities at Fort Belvoir, Virginia. All of the runup data were obtained on a plane, smooth 1 on 10 slope.

II. EXPERIMENTAL SETUP

1. Wave Tank and Generator.

The study was conducted in a wave tank, 2 feet deep (0.61 meter), 1.5 feet wide (0.46 meter), and 72 feet long (22 meters) with a water depth of 1.25 feet (0.38 meter). A fiberglass board with built-in gage circuitry formed part of a plane, smooth 1 on 10 slope, terminating on the tank floor about 42 feet (12.8 meters) from the mean position of the piston-type wave blade. A schematic cross-sectional view of the wave tank and the runup slope is shown in Figure 1.

The wavemaker was hydraulically actuated and controlled by signals from one or more function generators; one function generator made monochromatic waves, and combined signals from two or three function generators produced irregular waves. A typical section from a wave record having three monochromatic components is shown in Figure 2. The wave tank and generator are discussed in Coastal Engineering Research Center, 1968.

2. Runup Gage.

The runup gage was an adaption of a relay-type, step-resistance wave gage described by Williams (1969). Sensor contacts for the gage were copper strips several thousandths of an inch thick, spaced one-tenth of a foot (30.5 millimeters) apart, and bonded to the fiberglass board forming the runup slope face. On the 1 on 10 slope, the gage had a vertical runup resolution of about 0.01 foot (3 millimeters). It was self-calibrating with a linear response, operated well in freshwater, had a relatively smooth surface, and responded quickly to record the complex runup patterns

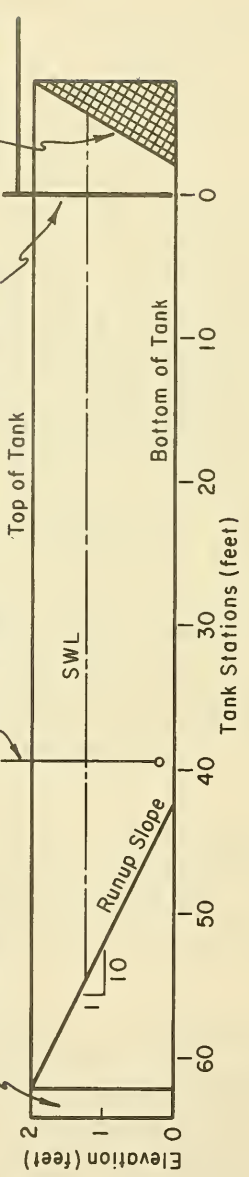


Figure 1. A schematic cross-sectional view of wave tank and runup slope.

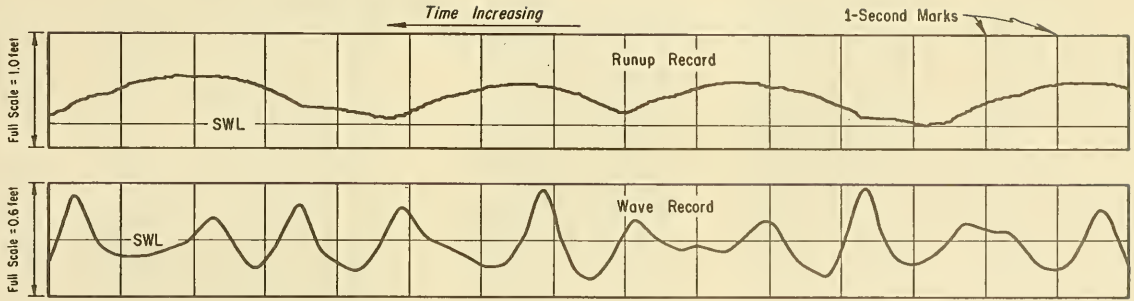


Figure 2. A typical section of a wave record with three monochromatic components.

of irregular waves. The gage was developed because runup maxima caused by irregular waves have proven difficult to accurately record by visual observation. The gage provided a complete record of the time history of the location of the air-water interface on the runup board. Sections of runup record and the record of the causitive waves are shown in Figure 2. Incident wave conditions were monitored by a parallel wire-resistance wave gage located 2.5 feet (0.76 meter) seaward of the toe of the 1 on 10 slope. The location of the runup board and the position of every 10th runup sensor contact is shown in Figure 3.

A disadvantage of the runup gage was that it was impossible to tell from the runup record if there was a malfunction in the relays. The gage used 120 mechanical relays and a few relays had to be adjusted every week or so to obtain proper operation. No runup data were collected until all relays were operative. Another problem was the copper runup sensor contacts that needed cleaning about every 2 weeks for proper operation. Cleaning the contacts required draining the tank which was inconvenient.

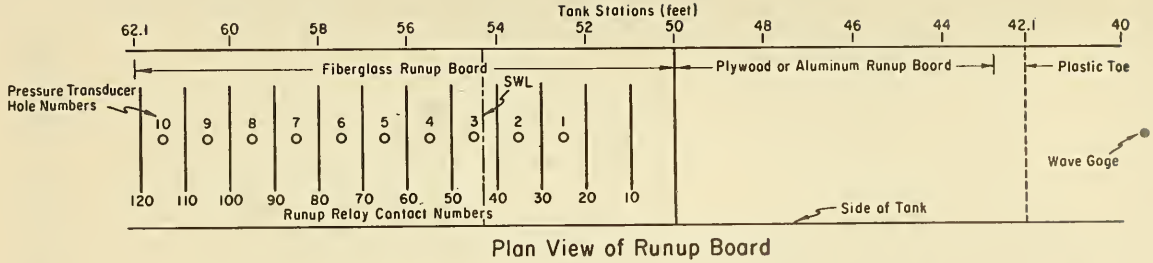
3. Runup Structure.

The slope seaward of the fiberglass runup board forming the runup gage was originally a 0.5-inch-thick plywood board which was later replaced with a sheet of 0.25-inch aluminum. The plywood lacked sufficient stiffness and was difficult to keep properly alined due to continual warping. The plywood also seemed to encourage the growth of algae. The aluminum sheet corrected these problems; however, aluminum oxide formed on the submerged surface of the sheet and had to be removed from time to time. The location of the plywood board and aluminum sheet is shown in Figure 3. The supports for the runup slope were made of wood.

4. Pressure Transducers.

Pressure transducers were used with the runup gage to determine their usefulness in estimating the limits of runup, the vertical thickness of the runup wedge, and the overtopping potential. The transducers were located in a dry chamber of the wave tank behind the runup board and connected to the face of the runup board by flexible plastic hoses. Only four pressure transducers could be used at one time but there were 10 locations where they could be used. The four locations of the transducers used in this study were designated 1, 3, 4, and 5. Elevations of hose openings on the runup board, relative to the stillwater level, were -0.2, 0.0, +0.1, and +0.2 foot for locations 1, 3, 4, and 5, respectively. The four pressure transducers were each mounted on a lorry gage so they could easily be raised and lowered to obtain static pressure calibrations. The location of the transducers and hoses is shown in Figure 3.

The transducers had a full-scale range of either 0.5 or 1.0 pound per square inch. They were very sensitive and could detect a thinner layer of water on the runup board than detected by the runup gage. Normally, a depth of about one-eighth of an inch of water over the runup contact was necessary to activate a relay of the runup gage. There was little trouble



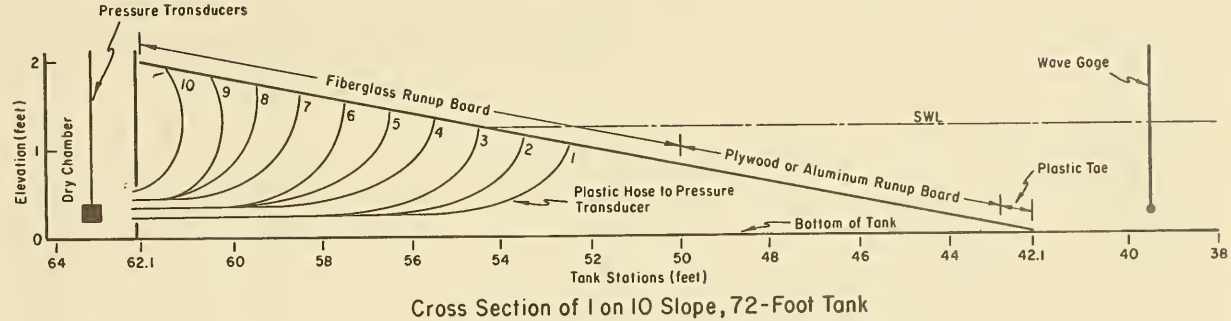


Figure 3. Plan and profile views of the runup slope.

getting good pressure records; however, it was sometimes necessary to eliminate air in the connecting hoses. Occasionally, wave action would induce small currents behind the runup board which caused the connecting hoses to sway back and forth slightly, resulting in small pressure fluctuations that were not due to runup.

III. TEST CONDITIONS AND PROCEDURES

Tests conducted during this study included a series of runs with only monochromatic waves, and a series with both monochromatic and irregular waves. In testing with monochromatic waves, the periods used were 0.72, 1.00, 1.55, 1.85, 2.63, 3.65, and 4.70 seconds. These conditions and others had previously been tested by Saville (1956) and Savage (1958). The procedure used by Saville and Savage of running the waves in bursts to reduce the influence of wave reflection, was also adopted for the monochromatic waves but not the tests comparing the runup of monochromatic waves to irregular waves. The running of tests similar to Saville and Savage was done to gain experience in using the runup gage and, if their results could be reproduced, gain confidence in the gage. The wave conditions and runup data collected by Saville (1956) and Savage (1958) are given in Table 1; the corresponding data obtained during this study are given in Table 2.

Table 1. Runup data by Saville (1956) and Savage (1958).

T (seconds)	H (feet)	R (feet)	T (seconds)	H (feet)	R (feet)
0.72	0.040	0.027	2.63	0.032	0.099
0.72	0.114	0.046	2.63	0.088	0.178
0.72	0.150	0.055	2.63	0.140	0.225
0.72	0.192	0.063	2.63	0.210	0.276
1.00	0.060	0.050	3.65	0.024	0.053
1.00	0.176	0.090	3.65	0.058	0.135
1.00	0.280	0.108	3.65	0.092	0.189
1.00	0.396	0.125	3.65	0.152	0.292
1.55	0.046	0.075	4.70	0.016	0.046
1.55	0.128	0.145	4.70	0.044	0.124
1.55	0.210	0.173	4.70	0.066	0.185
1.55	0.360	0.205	4.70	0.112	0.268
1.85	0.048	0.090	----	-----	-----
1.85	0.124	0.153	----	-----	-----
1.85	0.204	0.192	----	-----	-----
1.85	0.320	0.257	----	-----	-----

NOTE: Smooth 1 on 10 slope, water depth = 1.25 feet (0.38 meter).

The wave conditions used to compare the runup of monochromatic and irregular waves are shown in Table 3. Data from each of the wave conditions were collected during one long continuous run. When wave conditions

Table 2. Runup data obtained during the study period.

T (seconds)	H (feet)	R (feet)	T (seconds)	H (feet)	R (feet)
0.72	0.044	0.030	2.63	0.056	0.110
0.72	0.088	0.045	2.63	0.100	0.175
0.72	0.138	0.055	2.63	0.144	0.240
0.72	0.183	0.060	2.63	0.192	0.290
0.72	0.230	0.070	2.63	0.200	0.330
			2.63	0.300	0.330
1.00	0.048	0.050	2.63	0.360	0.340
1.00	0.096	0.070	2.63	0.432	0.360
1.00	0.112	0.080			
1.00	0.124	0.115	3.65	0.060	0.125
1.00	0.150	0.090	3.65	0.112	0.235
1.00	0.198	0.100	3.65	0.180	0.330
1.00	0.290	0.120	3.65	0.232	0.410
1.00	0.336	0.150	3.65	0.304	0.450
1.00	0.360	0.140	3.65	0.370	0.460
			3.65	0.420	0.510
1.55	0.044	0.070	3.65	0.468	0.550
1.55	0.096	0.100			
1.55	0.144	0.135	4.70	0.030	0.095
1.55	0.186	0.160	4.70	0.068	0.220
1.55	0.232	0.170	4.70	0.090	0.330
1.55	0.290	0.210	4.70	0.128	0.430
1.55	0.336	0.205	4.70	0.168	0.500
1.55	0.384	0.220	4.70	0.220	0.540
			4.70	0.264	0.570
1.85	0.040	0.080			
1.85	0.096	0.120	----	-----	-----
1.85	0.150	0.160	----	-----	-----
1.85	0.198	0.200	----	-----	-----
1.85	0.240	0.220	----	-----	-----
1.85	0.300	0.250	----	-----	-----
1.85	0.360	0.270	----	-----	-----
1.85	0.408	0.300	----	-----	-----

NOTE: Smooth 1 on 10 slope, water depth = 1.25 feet (0.38 meter).

Table 3. Comparison of runup caused by monochromatic and irregular waves.

Run No.	Record Length (seconds)	Wave Conditions	D_{rms} (feet)	H_s (feet)	T_z (seconds)	ϵ	$\frac{D(max)}{D_{rms}}$	R (feet)	R(max) (feet)	$\frac{R(max)}{D_{rms}}$	$\frac{N_R}{N_c}$
1	21.2	A	0.052	0.153	1.09	0.22	1.60	0.086	0.105	2.02	0.75
2	31.6	B	0.097	0.281	1.58	0.0	1.71	0.190	0.255	2.63	1.00
3	29.0	C	0.032	0.102	2.00	0.26	1.81	0.111	0.125	3.91	0.93
4	40.0	A+B	0.107	0.392	1.57	0.24	2.36	0.256	0.405	3.79	0.57
5	40.0	A+C	0.060	0.205	1.11	0.0	2.18	0.188	0.265	4.42	0.51
6	40.0	B+C	0.101	0.352	1.56	0.0	2.53	0.224	0.295	2.92	0.82
7	40.0	A+B+C	0.108	0.393	1.52	0.45	3.19	0.324	0.545	5.05	0.44
8	40.0	A+B+C	0.110	0.422	1.57	0.42	3.06	0.296	0.425	3.86	0.42

NOTES: Smooth 1 on 10 slope, water depth = 1.25 feet (0.38 meter).

Wave conditions (components)

A period = 1.11 seconds, eccentric = 0.75 inch (17.1 millimeters)
B period = 1.56 seconds, eccentric = 2 inches (50.8 millimeters)
C period = 2.02 seconds, eccentric = 1 inch (25.4 millimeters)

were changed to form subruns during this lengthy run, at least 3 minutes were allowed before data were collected to permit the wave and runup conditions to "stabilize." The subruns are designated as runs 1 to 8 in Table 3.

Since the runup gage and board occupied the entire width of the tank, there was no room for wave absorber material and wave filters were not used. For the long-period monochromatic waves used to simulate the conditions of Saville (1956) and Savage (1958), a standing wave pattern was noted in the tank during a wave burst. However, the results of this study are largely confined to wave periods of about 2 seconds or less where there was little visual evidence of reflection. The magnitude of the reflection was not measured.

The seven unique wave conditions and one replicate of increasing complexity (runs 1 to 8, Table 3) are parameterized by giving the root mean square water surface displacement, D_{rms}, the significant wave height, H_s, the mean zero up-crossing period, T_z, the spectral width parameter, ϵ, and the ratio of the highest crest, D(max) to D_{rms}. The length of record used to compute the various parameters is also shown in Table 3. D_{rms} was computed from the wave record digitized at a rate of five times per second. H_s is the average of the highest one-third of the waves. T_z, calculated by Draper's (1966) method, is the length of record in seconds divided by the number of zero up-crossings. The spectral width parameter, was calculated from the formula,

$$\epsilon^2 = 1 - (N_z/N_c)^2 \ ,$$

where N_z/N_c is the ratio of zero up-crossings to wave crests. Epsilon, ϵ, is also developed and discussed, in terms of the moments of the wave spectrum (Cartwright and Longuet-Higgins, 1956), and can be used as a rough measure of the irregularity of a wave record (Draper, 1966).

The average elevation of the runup crests, R, and the maximum observed runup elevation, R(max), are the two runup parameters given in Table 3; both elevations are referenced to the stillwater level. R has been extensively used in studies of runup caused by monochromatic waves (Saville, 1956; Savage, 1958). R(max) is of interest because it is generally the extreme values of runup that are needed for design purposes. The two runup parameters also provide a useful way to compare runup caused by monochromatic and irregular waves. Other runup parameters, such as the elevation exceeded by 2 percent of the runup crests (van Oorschot and d'Angremond, 1968), are not tabulated. The record lengths used in this study were too short to allow meaningful interpolation or extrapolation of the runup distributions for extreme values.

Table 4 gives some data to supplement Table 3, i.e., average and maximum wave heights, and the temporal distribution of runup.

Table 4. Comparison of runup of monochromatic and irregular waves.

Run No.	Record Length (seconds)	Wave Conditions	T_z (seconds)	D_{rms} (feet)	$\overline{H}$ (feet)	H_s (feet)	H(max) (feet)	R (feet)	R(min) (feet)	R_{85} (feet)	R_{50} (feet)	R_{15} (feet)	R(max) (feet)
1	21.2	A	1.09	0.052	0.148	0.153	0.156	0.086	0.055	0.057	0.065	0.079	0.105
2	31.6	B	1.58	0.097	0.271	0.281	0.294	0.190	0.075	0.124	0.160	0.200	0.255
3	29.0	C	2.00	0.032	0.091	0.102	0.108	0.111	0.025	0.047	0.080	0.102	0.125
4	40.0	A+B	1.57	0.107	0.286	0.392	0.432	0.256	-0.005	0.085	0.205	0.308	0.405
5	40.0	A+C	1.11	0.060	0.150	0.205	0.240	0.188	0.025	0.066	0.145	0.203	0.265
6	40.0	B+C	1.56	0.101	0.275	0.352	0.390	0.224	-0.045	0.067	0.180	0.249	0.295
7	40.0	A+B+C	1.52	0.108	0.257	0.393	0.504	0.324	-0.045	0.068	0.210	0.350	0.545
8	40.0	A+B+C	1.57	0.110	0.283	0.422	0.528	0.296	-0.005	0.112	0.210	0.350	0.425

NOTES: Smooth 1 on 10 slope, water depth = 1.25 feet (0.38 meter).

Wave conditions (components)

A period = 1.11 seconds, eccentric = 0.75 inch (19.1 millimeters)
B period = 1.56 seconds, eccentric = 2 inches (50.8 millimeters)
C period = 2.02 seconds, eccentric = 1 inch (25.4 millimeters)

IV. OBSERVATIONS AND RESULTS

A comparison of the monochromatic wave runup data using the runup board-gage and the runup data collected by Saville (1956) and Savage (1958) is shown in Figure 4. In Figure 4, the ratio of the runup divided by the wave height, R/H, is plotted versus the wave height divided by the square of the wave period, H/T^2. The agreement between sources indicates that the gage provides a measure of runup that compares well with previous measures. Gage runup values were also consistent with visual runup observations taken simultaneously.

The differences in the relative runup between sources, shown in Figure 4 for values of H/T^2 less than 0.01, are probably due to the influence of secondary waves (Multer, 1973). Multer noted that secondary waves cause variations in runup that are a function of the distance between the runup slope and the wave blade. The exact distance between the wave blade and slope for the tests conducted by Saville (1956) and Savage (1958) is not known but it was probably different than the distance used in this study. Secondary crests are observed for relatively long waves, i.e., depth to wavelength ratios less than 0.09 (Madsen, Mei, and Savage, 1970), which would include the wave periods of 2.63, 3.65, and 4.70 seconds used in these studies. Most of the wave conditions using the above periods had values of H/T^2 less than 0.01 where the runup discrepancies between sources occurred.

The runup gage records showed that the runup time history had broad, flat crests and short, sharp troughs, a shape similar to a trochoidal wave profile with the crests and troughs reversed. A section of the record for run 8 of Table 3 and the record of the incident wave conditions are shown in Figure 2. For monochromatic waves, the trochoidal shape of the runup record was more evident than for run 8 with irregular waves.

In comparing wave and runup records, it was found that for some monochromatic wave conditions there was not a clearly defined runup crest for every incident wave crest. For a wave period of 0.72 second there was approximately one runup crest for every two wave crests. The ratio of runup crests to wave crests tended to increase as the wave period increased until it reached a ratio of 1, somewhere between periods of 1 and 1.5 seconds. There was also a loss of runup crests for irregular waves which was surprisingly great when compared to the loss associated with their monochromatic components. Table 3 gives the ratio of runup crests, N_R, to wave crests N_c. Run 3 in Table 3, with a zero up-crossing period of 2 seconds, shows a small loss of runup crests which was not evident from visual observations. Inspection of the wave record for run 3 shows a slight perturbation in each of the troughs which was probably caused by wave reflection from the slope, since the period appeared to be too short for secondary waves. This perturbation was large enough (about 1 percent full scale) at one time to be counted as a crest which caused run 3 to have one runup crest less than the number of wave crests.

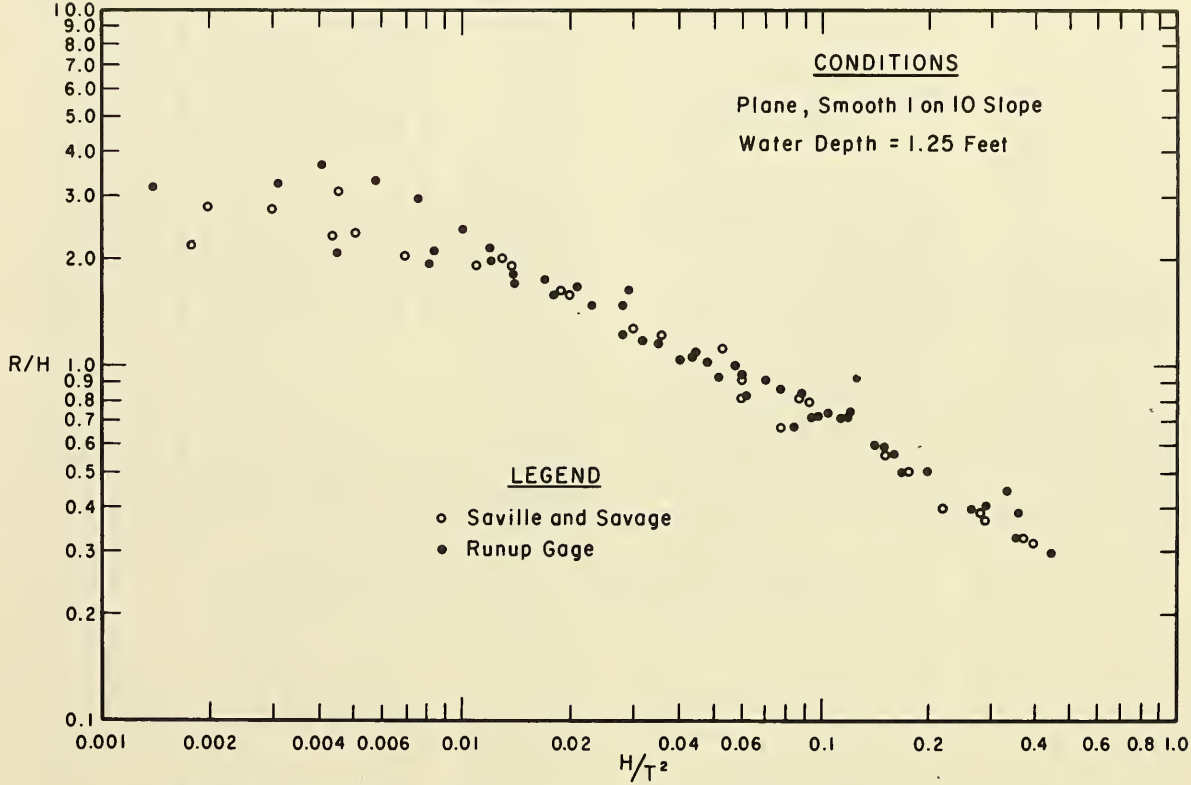


Figure 4. Comparison of runup data by Saville (1956) and Savage (1958) with the runup gage.

Irregular waves sometimes coalesce in the surf zone and travel up the slope as a single entity. Runup crests are also lost when the runup-rundown cycle for one wave is not completed before the arrival of the next wave near the stillwater line. Waves arriving before the completed rundown cycle retard and confuse the return flow but do not necessarily cause a distinct runup crest. This piling up of water around the stillwater line is a component of the wave setup commonly observed in the surf zone. The phenomenon where runup crests are lost should logically depend on the slope and roughness of the runup board as well as the wave conditions. The observation that many waves caused no runup maximum for some wave conditions confirms the complexity of wave action in the surf zone and merits further investigation. A similar loss of runup crests was noted by Webber and Bullock (1968).

Table 3 shows that the difference between the maximum runup, R(max), and R becomes greater as the waves becomes more complex. There is also an increase in the dimensionless extreme runup, $R(max)/D_{rms}$, as the wave conditions become more complex. The average value of $R(max)/D_{rms}$ increases from 2.85 to 3.71 to 4.46 for one, two, and three component waves, respectively. These findings are consistent with those of van Oorschot and d'Angremond (1968) who noted an increase in normalized extreme runup values associated with an increase in the width of the wave spectrum.

The irregular arrival of waves of different amplitudes into the surf zone and their interaction with the return flow of previous waves create opportunities for unusually high runup which do not occur for monochromatic waves. Another reason for high extreme values of runup for irregular waves is the growth of the highest wave crests as waves progress from monochromatic to complex. Table 3 shows the growth of the highest crest, D(max), relative to D_{rms} as the wave conditions become more complex. Visual observations indicated that runup was influenced more by crest height than wave height.

Runs 7 and 8 were intended to be replicates; however, the R(max)'s differ significantly. A record length of 40 seconds is probably too small to establish reproducible extreme values for irregular waves and their runup. A zero value for ε for runs 5 and 6 also appears to be due to the short-record length since the two component waves would be expected to produce some crests below the stillwater level (negative crests) which would cause ε to be nonzero. One negative crest due to reflection caused ε to be 0.26 for run 3. Epsilon would normally be zero for a monochromatic wave with no reflection. The record for run 1 was truncated such that there was one less zero crossing (equivalent to one-half a zero up-crossing by Draper's (1966) method) than wave crest, causing that monochromatic wave to also have a nonzero value for ε. The short-record length and wave reflection have caused the monochromatic waves to appear more irregular than the two-component waves when judged by ε in Table 3.

Pressure records were also collected for the wave conditions shown in Table 3 and digitized at a rate of 10 per second. Four pressure transducers

were used and located at positions designated 1, 3, 4, and 5 in Figure 3. A summary of the pressure data organized by wave conditions is given in Table 5. The same data organized by transducer location are given in Table 6. The pressure data are given as pressure head, in feet of water, relative to the stillwater level as determined from static calibration.

An attempt was made to compare extreme values in the pressure record to extreme values of runup but little correlation was noted. However, the short-record lengths may have contributed to the lack of correlation.

V. RECOMMENDATIONS

1. Runup Gage.

The runup gage, while generally performing well, could be improved. The reliability of the runup gage could possibly be improved by replacing the mechanical relays with solid-state relays. The use of solid-state relays might make it feasible to have greater resolution of the runup by using more runup contacts per slope length than is possible with mechanical relays. Closer spacing of contacts would be necessary to maintain the same resolution (0.01 foot) on a steeper slope. Some type of circuit logic which could identify relay malfunctioning would also be beneficial.

2. Data Sample Sizes.

Analysis has shown that the sample sizes used to compile Table 3 were too small. The data analysis in Table 3 represents the upper limit of complexity that can be reduced manually. For a quantitative investigation of runup caused by irregular waves similar to the type encountered in coastal waters, larger sample sizes of the relevant parameters will be required. It is recommended that a computer-based data acquisition system be used in future CERC studies of irregular wave runup.

3. Pressure Transducers.

The pressure transducers generally worked satisfactorily and required little maintenance. Visual and photographic observations indicate the thickness of the runup wedge can be measured from the pressure transducer records. Future research should include quantitative verification of the relationship between the pressure record and the thickness of the runup layer on the slope.

Pressure transducers were incorporated into this phase of the runup study primarily to gain familiarity with their use and to assess their potential value to the more advanced work on runup and overtopping. The transducers used below the stillwater level can monitor waves shoaling and coalescing over the runup slope and other surf processes such as wave setup and setdown. Pressure transducers located above the stillwater level on the runup slope should be useful in predicting potential overtopping at their elevation. Their usefulness in predicting overtopping will be verified through calibration during subsequent phases of this study.

Table 5. Pressure data organized by wave conditions.

Run No.	Record Length (seconds)	Wave Condition	H_s (feet)	T_z (seconds)	Pressure Transducer No.	Pressure head of water relative to stillwater level (feet)					
						Min	P 85	P 50	P 15	Max	Mean
1	21.2	A	0.153	1.09	1	-0.072	-0.054	-0.032	+0.078	+0.114	-0.005
1	21.2	A	0.153	1.09	3	+0.009	+0.016	+0.033	+0.056	+0.084	+0.036
1	21.2	A	0.153	1.09	4	+0.099	+0.099	+0.100	+0.103	+0.109	+0.102
1	21.2	A	0.153	1.09	5	+0.194	+0.196	+0.198	+0.200	+0.204	+0.199
2	31.6	B	0.281	1.58	1	-0.084	-0.061	-0.007	+0.058	+0.276	+0.002
2	31.6	B	0.281	1.58	3	+0.016	+0.033	+0.062	+0.098	+0.159	+0.068
2	31.6	B	0.281	1.58	4	+0.101	+0.109	+0.119	+0.134	+0.189	+0.123
2	31.6	B	0.281	1.58	5	+0.196	+0.196	+0.200	+0.207	+0.234	+0.203
3	29.0	C	0.102	2.00	1	-0.072	-0.053	-0.017	+0.042	+0.108	0.000
3	29.0	C	0.102	2.00	3	-0.001	+0.009	+0.029	+0.048	+0.066	+0.030
3	29.0	C	0.102	2.00	4	+0.099	+0.101	+0.104	+0.112	+0.126	+0.107
3	29.0	C	0.102	2.00	5	+0.199	+0.200	+0.201	+0.203	+0.206	+0.203
4	40.0	A+B	0.392	1.57	1	-0.102	-0.062	-0.007	+0.081	+0.252	+0.010
4	40.0	A+B	0.392	1.57	3	-0.021	+0.028	+0.057	+0.101	+0.189	+0.062
4	40.0	A+B	0.392	1.57	4	+0.099	+0.103	+0.123	+0.148	+0.199	+0.127
4	40.0	A+B	0.392	1.57	5	+0.194	+0.199	+0.208	+0.225	+0.246	+0.212
5	40.0	A+C	0.205	1.11	1	-0.114	-0.070	-0.022	+0.044	+0.174	-0.010
5	40.0	A+C	0.205	1.11	3	+0.001	+0.014	+0.032	+0.064	+0.226	+0.039
5	40.0	A+C	0.205	1.11	4	+0.099	+0.102	+0.113	+0.128	+0.159	+0.116
5	40.0	A+C	0.205	1.11	5	+0.194	+0.198	+0.202	+0.209	+0.221	+0.204
6	40.0	B+C	0.352	1.56	1	-0.102	-0.056	-0.005	+0.084	+0.258	+0.010
6	40.0	B+C	0.352	1.56	3	-0.001	+0.016	+0.060	+0.111	+0.211	+0.067
6	40.0	B+C	0.352	1.56	4	+0.101	+0.104	+0.126	+0.163	+0.239	+0.134
6	40.0	B+C	0.352	1.56	5	+0.199	+0.200	+0.207	+0.220	+0.251	+0.211
7	40.0	A+B+C	0.393	1.52	1	-0.114	-0.069	-0.009	+0.078	+0.306	+0.009
7	40.0	A+B+C	0.393	1.52	3	-0.006	+0.009	+0.064	+0.128	+0.244	+0.073
7	40.0	A+B+C	0.393	1.52	4	+0.101	+0.104	+0.135	+0.187	+0.269	+0.145
7	40.0	A+B+C	0.393	1.52	5	+0.194	+0.203	+0.211	+0.242	+0.346	+0.222
8	40.0	A+B+C	0.422	1.57	1	-0.090	-0.056	-0.002	+0.080	+0.306	+0.017
8	40.0	A+B+C	0.422	1.57	3	-0.001	+0.014	+0.057	+0.106	+0.229	+0.062
8	40.0	A+B+C	0.422	1.57	4	+0.101	+0.105	+0.129	+0.161	+0.241	+0.135
8	40.0	A+B+C	0.422	1.57	5	+0.191	+0.201	+0.210	+0.230	+0.271	+0.215

NOTE: Pressure transducer locations are shown in Figure 3, and symbols defined in Symbols and Definitions.

Table 6. Pressure data organized by transducer location.

Run No.	Record Length (seconds)	Wave Condition	H_s (feet)	T_z (seconds)	Pressure Transducer No.	Pressure head in feet of water relative to stillwater level					
						Min	P 85	P 50	P 15	Max	Mean
1	21.2	A	0.153	1.09	1	-0.072	-0.054	-0.032	+0.078	+0.114	-0.005
2	31.6	B	0.281	1.58	1	-0.084	-0.061	-0.007	+0.058	+0.276	+0.002
3	29.0	C	0.102	2.00	1	-0.072	-0.053	-0.017	+0.042	+0.108	0.0
4	40.0	A+B	0.392	1.57	1	-0.102	-0.062	-0.007	+0.081	+0.252	+0.010
5	40.0	A+C	0.205	1.11	1	-0.114	-0.070	-0.022	+0.044	+0.174	-0.010
6	40.0	B+C	0.352	1.56	1	-0.102	-0.056	-0.005	+0.084	+0.258	+0.010
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4	40.0	A+B	0.392	1.57	3	-0.021	+0.028	+0.057	+0.101	+0.189	+0.062
5	40.0	A+C	0.205	1.11	3	+0.001	+0.014	+0.032	+0.064	+0.226	+0.039
6	40.0	B+C	0.352	1.56	3	-0.001	+0.016	+0.060	+0.111	+0.211	+0.067
7	40.0	A+B+C	0.393	1.52	3	-0.006	+0.009	+0.064	+0.128	+0.244	+0.073
8	40.0	A+B+C	0.422	1.57	3	-0.001	+0.014	+0.057	+0.106	+0.229	+0.062
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3	29.0	C	0.102	2.00	4	+0.099	+0.101	+0.104	+0.112	+0.126	+0.107
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4	40.0	A+B	0.392	1.57	5	+0.194	+0.199	+0.208	+0.225	+0.246	+0.212
5	40.0	A+C	0.205	1.11	5	+0.194	+0.198	+0.202	+0.209	+0.221	+0.204
6	40.0	B+C	0.352	1.56	5	+0.199	+0.200	+0.207	+0.220	+0.251	+0.211
7	40.0	A+B+C	0.393	1.52	5	+0.194	+0.203	+0.211	+0.242	+0.346	+0.222
8	40.0	A+B+C	0.422	1.57	5	+0.191	+0.201	+0.210	+0.230	+0.271	+0.215

NOTE: Pressure transducer locations are shown in Figure 3, and symbols defined in Symbols and Definitions.

4. Tank Width and Wave Reflection.

Irregular waves must be generated by running continuously for relatively long time periods to simulate coastal wave conditions and to obtain a satisfactory sample of the extreme values of runup. Generating waves continuously for 5 to 10 minutes may be desirable. The influence of wave reflection in a narrow wave tank without an absorber beach or filter will be difficult to evaluate under continuous running conditions. Reflection is affected by the wave period, wave height, water depth, and the slope and roughness of the runup board. All of these factors can be expected to influence the modification of the generated waves and consequently the runup.

Reflection shifts the energy distribution in the wave spectrum toward lower frequencies since long waves reflect better than short waves. Long waves runup more efficiently than short waves; therefore, it is probable that reflection has considerable influence on the extreme values of the runup. Since the influence of reflection is inherently difficult to delineate, it is advisable in future experiments to reduce the influence of reflection as much as possible. It is recommended that future investigations of runup and overtopping caused by irregular waves be conducted in a relatively wide tank, using a generous part of the width for an absorber beach. Consideration should also be given to using a wave filter in the tank between the wave generator and the runup slope.

The recommendation for the use of a wide tank is not intended to preclude all use of narrow tanks. A narrow tank could be used to gain experience in using a data acquisition system, developing instrumentation and test procedures, and learning how to simulate coastal wave conditions. All of these elements are important to a comprehensive study of wave runup and overtopping.

5. Secondary Waves.

Because of the influence of secondary waves on runup noted by Multer (1973), an attempt should be made to detect their influence on irregular waves. It is recommended that some tests be conducted, which are otherwise replicates, using different distances between the slope and the wave blade.

6. Data Analysis and Theoretical Development.

Some high runup values are caused by high crests instead of high wave heights. Since, from a theoretical point of view it may be easier to work with crest elevations than wave heights (Cartwright and Longuet-Higgins, 1956), an investigation as to how well this incident wave parameter correlates to extreme values of runup would be useful.

The loss of runup crests and visual observations of runup both in the laboratory and in the field indicate that a large runup is often produced through the complicated interaction of two or three waves. Through the

use of a computer-controlled data acquisition system it may be possible to identify the chain of events which cause high runups. This approach would be somewhat novel since it would be considering the characteristics of two or three waves which interact to produce one runup.

In addition to the above approaches for predicting runup, the methods of Battjes (1971) and van Oorschot and d'Angremond (1968) should be investigated. Battjes' method of runup prediction was based on the joint distribution of wave heights and periods, and was similar to Saville's (1962) approach except Battjes produced a formula of the type developed by Hunt (1959). van Oorschot and d'Angremond (1968) also used Hunt's formula; however, their approach was based on the spectral characteristics of the waves.

VI. SUMMARY AND CONCLUSIONS

The wave runup board-gage developed for this study generally worked satisfactorily. Without the runup gage it would have been impossible to accurately record the runup extremes caused by irregular waves. In addition to providing the runup maximums and minimums, the runup gage gave a complete time history of the air-runup interface on the slope. Improved instrumentation techniques should permit the development of an improved runup gage similar to the one used in this study.

The maximum runups of irregular waves are greater than those of monochromatic waves even when the runups are normalized by dividing by the root mean square water surface displacement, i.e., standard deviation of the wave record. Observations of irregular wave runup suggest the following two general reasons why it is greater than the runup of monochromatic waves: (a) the growth of the largest waves (or probably more significant, the growth of the highest crests) as measured by root mean square water surface displacement, as conditions progress from monochromatic to complex; and (b) the irregular arrival of waves of different amplitudes near the stillwater line, and their interaction with the return flow of previous runups, occasionally create the opportunity for unusually high runups.

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25 p. : ill. (Miscellaneous paper – Coastal Engineering Research Center ; no. 12-75)
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